NITROGEN ENRICHMENT OF TWO FOREST ECOSYSTEMS BY RED ALDER

BY

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SUMMARY

Litterfall weight and N content was determined in forest stands of (1) red alder (*Alnus rubra*), a tree capable of symbiotic fixation of atmospheric N; (2) conifers *Pseudotsuga menziesii*, *Tsuga heterophylla*, and *Picea sitchensis*; and (3) a mixture of alder and conifers. Chemical properties were determined for soil and for throughfall precipitation. All trees grew on a Sol Brun Acide soil, derived largely from Eocene siltstone.

Between-stand relationships were alder > mixed > conifer for N (percent of dry weight) in litterfall and precipitation and for N (pounds per acre) in soil and precipitation; alder = mixed > conifer for N weight in litterfall; and conifer > alder = mixed for C:N ratio of litter. Soil N (pounds per acre) to 36 inches was: alder, 16,680; mixed stand, 12,640; and conifer, 11,720.

Weight of N (pounds per acre per year) cycled in litterfall was: mixed stand, 104; alder, 100; and conifer, 32. Current net accretion to N capital of the site in litterfall and throughfall precipitation—attributed to N fixation by alder—was, for the mixed and alder forest types, respectively, 74 and 70 pounds per acre per year.

In the coastal Oregon study area, where soil N is perhaps near the maximum attainable in a forest environment, presence of red alder led to a threefold increase in the amount of N circulating in the ecosystem.

INTRODUCTION

Red alder (*Alnus rubra Bong.*) is a nonleguminous, nitrogen-fixing woody plant and the major hardwood tree species in the Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) region of the Pacific Northwest. Information on the soil-improving function of red alder and other members of its genus has been summarized (Tarrant 1964),[1] and results of a number of recent investigations have been reported for red alder and several other species of *Alnus* (Trappe et al. 1968).

Nitrogen is of special interest in connection with forest soil fertility in the Pacific Northwest because it is the only nutrient element thus far found to appreciably stimulate growth of Douglas-fir when applied as fertilizer (Gessel et al. 1965). The carbon to nitrogen ratio is also important because it is one measure of the potential rate at which N and other nutrient elements in litterfall will be released and made available for use by plants.

As part of an investigation[2] of the effects of red alder on forest soil fertility, we report herein results of a 3-year comparison of litterfall beneath stands of red alder; conifers — Douglas-fir, Sitka spruce (*Picea sitchensis* (Bong.) Carr.), and western hemlock (*Tsuga heterophylla* (Raf.) Sarg.); and a mixture of alder and conifers. Seasonal amounts of litterfall have been determined and quality of litterfall from the different forest types has been assessed as to total nitrogen concentration, total nitrogen weight, and carbon-nitrogen ratio.

We asked in this study: "What is the seasonal and yearly weight of litterfall beneath the three stands? What is the concentration of total N in the litterfall? What is the weight of total N returned to the soil seasonally and yearly beneath these stands? Is the C:N ratio of litterfall different between the several forest types?"

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[1] Names and dates in parentheses refer to Literature Cited, p 7.

[2] This study was supported in part by the National Science Foundation, Grant No. GB-3214.

STUDY METHODS

The study was conducted at the Station's Cascade Head Experimental Forest on the Oregon coast at latitude 45°3′ N., longitude 123°55′ W. Here, experimental plots were established during 1935-37 to compare growth of pure red alder, pure conifer, and a natural mixed stand of red alder and conifers. The area occupied by the plots was formerly agricultural land which was abandoned about 1925.

Trees on the plots are now about 40 years old and occupy the following basal area (square feet per acre): alders, 156; conifers, 268; and mixed stand, 221. Soils beneath all three stands are Sols Bruns Acides, developed on a deeply weathered, tuffaceous siltstone of Eocene epoch. Detailed morphological and chemical characteristics of the soils are described by Franklin et al. (1968).

In June 1964, 15 ¼-milacre litter traps were placed in each stand. Traps were located in five groups of three each around randomly selected, previously numbered trees on each plot. Distance and direction of the traps from the trees were also determined by random selection.

Litterfall, defined as all plant material falling on the sampling areas, was collected from the traps at 3-month intervals—June-August, September-November, December-February, and March-May. These collection periods are hereinafter referred to, respectively, as "summer," "autumn," "winter," and "spring."

Immediately after the litterfall was collected, it was ovendried to constant weight at 70°C. and weighed to the nearest 0.1 gram. Samples were then analyzed for total N by the Kjeldahl method (Association of Official Agricultural Chemists 1960), and for carbon by use of a medium temperature resistance furnace after the method of Allison et al. (1964).

RESULTS

Litterfall Weight

The mixed stand contained 860 trees per acre, appreciably more than either conifer (490 per acre) or alder (381 per acre) stands. The mixed stand also generated the greatest weight of litterfall per year (5,930 pounds per acre per year) (table 1). Conifer and alder stands produced almost equal amounts of litterfall (4,232 and 4,490 pounds per acre per year) which was only about three-fourths that in the mixed stand.

TABLE 1.—*Litterfall weight by forest type, year, and season of sampling, Cascade Head Experimental Forest, Oreg., 1964-67*
(In pounds per acre)

Forest type	Sample year	SEASON				Yearly total
		Spring	Summer	Autumn	Winter	
Mixed	1	678	1.097	2.307	3.031	7.113
	2	819	1.237	2.166	1.059	5.281
	3	857	695	3.202	642	5.396
	Average	785	1.010	2.558	1.577	5.930
Alder	1	443	917	2.072	1.270	4.702
	2	549	1.196	1.908	765	4.418
	3	449	527	2.885	492	4.353
	Average	480	880	2.288	842	4.490
Conifer	1	846	550	1.511	1.889	4.796
	2	979	728	1.639	944	4.290
	3	646	314	1.955	691	3.606
	Average	824	531	1.702	1.175	4.232

A review of 163 published reports (Bray and Gorham 1964) indicates for a wide range of tree species that litter production in "cool temperate forests" of the world ranges from 2,204 to 6,157 pounds per acre per year and averages about 3,000. A few estimates of litterfall weight have also been reported for the tree species we studied. Dimock (1958) found, for a site of comparatively low productivity, that Douglas-fir litterfall weight averaged 1,575 pounds per acre per year over 6 years. On a site near that studied by Dimock and of similar productivity, Rahman[3] measured litterfall weights (pounds per acre per year) of 1,475 for Douglas-fir and 1,562 for red alder. Owen (1954) reported annual litterfall of 1,822 pounds per acre per year beneath a 20-year-old Sitka spruce plantation in North Wales. Thus, it appears that the stands at Cascade Head Experimental Forest are in the upper range of litter production for forests of the temperate zone.

In each of the three forest types, average litterfall weight varied with season. This highly significant (99-percent level of probability) variation is attributed to weather differences between years. Differences in total yearly litterfall were highly significant for the conifer stand but not for the mixed or alder types. Deciduous alder loses all its foliage yearly, which makes for uniformity in weight of leaf fall over several consecutive years in these comparatively mature stands. In contrast, conifer needles are released as litterfall only slowly unless sharp temperature and moisture variations occur. Dimock (1958) found that extremely low temperatures greatly increased Douglas-fir litterfall; but over 4 years in which such extremes did not occur, the magnitude of difference between the lowest and highest yearly litterfall weight was only about 1.4 times — about the same difference we found.

[3] Rahman, A. H. A study of the movement of elements from tree crowns by natural litterfall, stem flow and leaf wash. (Unpublished M.F. thesis on file at Univ. Wash.) 1964.

There was also a highly significant season-year interaction for each of the three forest types. In other words, the seasonal effect varied from year to year. We attribute this season-year interaction to variations in weather patterns and timing of phenological events which, of course, differ from year to year.

Nitrogen Concentration and Accretion in Litterfall

In each of the three forest types, N concentration (percent of dry weight) varied with season and year (table 2) and the season-year interaction was also highly significant. Differences between seasons within a single year are to be expected in view of the cyclic migration of nutrients within the tree. Differences between

Table 2.—*Total N in litterfall by forest type, year, and season of sampling; Cascade Head Experimental Forest, Oreg., 1964-67*
(In percent of dry weight)

Forest type	Sample year	SEASON				Yearly average
		Spring	Summer	Autumn	Winter	
Alder	1	2.49	2.63	2.82	1.43	2.34
	2	2.58	2.25	2.32	1.44	2.15
	3	2.44	2.12	2.36	1.18	2.03
	Average	2.50	2.33	2.50	1.35	2.17
Mixed	1	2.00	2.36	2.47	.94	1.94
	2	1.88	2.03	1.98	1.23	1.78
	3	1.81	1.88	2.04	1.21	1.74
	Average	1.89	2.09	2.16	1.13	1.82
Conifer	1	.91	.85	.90	.66	.83
	2	.81	.68	.74	.78	.75
	3	.90	.68	.76	.81	.79
	Average	.87	.74	.80	.75	.79

years and between seasons between years can be attributed generally to slight shifts in time of phenological events from year to year and, probably more important, to differences in the physical composition of litterfall due to air temperature and wind intensity.

Over 3 years, average N concentration of alder litter was almost three times — and that of the mixed stand more than two times — that of conifer litterfall. During spring, summer, and autumn, N concentration in alder litterfall was more than three times that beneath the conifer stand, and mixed litterfall was nearly the same. In winter samples, the same qualitative relationships prevailed, but N concentration in both the alder-influenced stands was sharply reduced over that of the other three seasons. Absence of alder leaves and a preponderance of woody materials in winter litterfall undoubtedly influenced N concentration in winter samples. Although N concentration in alder leaves usually exceeds 2 percent, that of alder wood is only about 0.37 percent (Bollen 1953).

Weight of litterfall N (table 3) exhibited the same highly significant variations as were found for N concentration. Average yearly weight of N was almost the same for mixed and pure alder stands, 104 and 100 pounds per acre, but that of the conifer stand was only 32 pounds per acre.

A substantial portion of the N in alder and mixed-stand litterfall must be regarded as an accretion to nutrient capital. Yearly N accumulations in soil influenced by species of *Alnus* other than red alder range from 21 to 54 pounds per acre (Tarrant 1964), and an average over 30 years of 36 pounds per acre per year was reported for a plantation of red alder and Douglas-fir by Tarrant and Miller (1963). Over 268 pounds per acre of N may be added each year to an ecosystem dominated by red alder between tree ages 2 and 14 years, according to Newton et al. (1968). These authors also indicate that about 89 pounds per acre of N is brought down annually in red alder litterfall, an estimate substantiated by our study.

Table 3—*Total N in litterfall by forest type, year, and season of sampling; Cascade Head Experimental Forest, Oreg., 1964-67.*
(In pounds per acre)

Forest type	Sample year	SEASON				Yearly total
		Spring	Summer	Autumn	Winter	
Mixed	1	13.1	25.6	56.5	24.2	119.4
	2	14.9	24.9	42.6	13.3	95.7
	3	13.6	13.0	63.5	6.9	97.0
	Average	13.9	21.2	54.2	14.8	104.0
Alder	1	10.7	24.1	58.4	19.0	112.2
	2	13.9	26.9	44.2	10.6	95.6
	3	9.7	11.2	67.9	4.4	93.2
	Average	11.4	20.7	56.8	11.3	100.3
Conifer	1	7.9	4.6	14.0	11.3	37.8
	2	7.8	4.8	12.0	7.4	32.0
	3	4.9	2.1	14.3	5.4	26.7
	Average	6.9	3.8	13.4	8.0	32.2

We deducted the N content of conifer litterfall from that for both the alder and mixed stands to obtain a conservative estimate of the N that might be regarded as an addition to nutrient capital through symbiotic fixation of atmospheric N by red alder. On this basis, mixed-stand litterfall apparently provided an average annual N accretion to the study site of about 72 pounds per acre and alder litterfall provided about 69 pounds per acre. In the same stands, net annual N accretion in throughfall (leaf wash) and stemflow precipitation was, for mixed and pure alder stands respectively, about 1.8 and 2.4 pounds per acre (Tarrant et al. 1967). Thus, between the N accretion from litterfall and that of enriched throughfall precipitation, about 74 pounds per acre per year of N can be regarded as an addition to the mixed-stand ecosystem and about 70 pounds per year to that of the alder ecosystem.

Carbon-Nitrogen Ratio

Over all years and seasons, the C:N ratio of conifer litter averaged 69 (table 4), but that of alder (27) and the mixed stand (32) were both less than half that value. There was little difference between the C:N ratio of litterfall collected in spring, summer, or autumn seasons beneath either alder or the mixed stand, but the C:N ratio was always greatest in winter-collected samples. This difference is attributed to low-nitrogen limbwood in alder-influenced stands, which falls in especially great amounts during winter storms.

TABLE 4.—*Carbon:nitrogen ratio in litterfall by forest type, year, and season of sampling; Cascade Head Experimental Forest, Oreg., 1964-67.*

Forest type	Sample year	SEASON				Yearly average
		Spring	Summer	Autumn	Winter	
Conifer	1	57	64	60	85	67
	2	62	79	71	69	70
	3	60	80	72	69	70
	Average	60	74	68	74	69
Mixed	1	26	23	21	59	32
	2	30	26	27	44	32
	3	30	28	27	46	33
	Average	29	26	25	50	32
Alder	1	21	20	19	49	27
	2	21	23	22	37	26
	3	23	25	23	44	29
	Average	22	23	21	43	27

DISCUSSION

Soil N at the site we studied is probably near the limit of accumulation for forest soils of the Pacific Northwest. Beneath the conifer stand, soil N to a depth of 36 inches totaled 11,720 pounds per acre (Franklin et al. 1968). Beneath the mixed stand, the comparable value for soil N was 12,640 pounds per acre and beneath pure alder, it was 16,680 pounds per acre. These values, the highest yet reported for Pacific Northwest forest soils, are near the maxima found in the highly productive redwood (*Sequoia sempervirens* (D. Don) Endl.) region of northern California (Cooper 1965).

A number of investigators, including Zavitkovski and Newton (1968), have shown that N-fixation by alder seedlings is reduced in the presence of high levels of combined N. Although our data for large trees neither support nor deny this finding, it is evident that even under conditions of very high total soil N, alder fixed large quantities of N. All trees on the study site began as natural regeneration on a forest clearing which had been in pasture for a number of years. After about 40 years of tree growth, soil beneath alder had 4,960 pounds per acre more N than that under conifers — indication of an average annual accretion to soil N of about 124 pounds per acre.

Although this early-established study area included only one plot for each forest type and thus allowed no possibility for statistical comparisons between stands, our observations agree very closely with those of Newton et al. (1968), who estimated that as much as 4,460 pounds per acre of litter is deposited annually beneath alder and that about 89 pounds per acre of N is added to the soil in this litterfall. The difference between the average N accretion of 124 pounds per acre per year in soil beneath pure alder over 40 years and the current accretion of 70 pounds per acre from alder litterfall and enriched precipitation suggests that the rate of N-fixation in stands we studied must at one time have been substantially greater than it is now.

Newton et al. (1968) measured annual N-fixation rates of as much as 286 pounds per acre in dense stands of red alder ranging from 2 to 14 years old, and concluded that equilibration of the N-fixation rate in soil tended to occur before tree age 20 years. Rates of N-fixation were substantiated by greenhouse studies (Zavitkovski and Newton 1968) which indicated that annual N-fixation by red alder could approach 89 pounds per acre during the first year of growth and reach as much as 186 pounds per acre per year in 30-year-old stands. These rates of fixation, the highest yet reported for red alder, appear to be entirely possible in light of our findings, which do not include N content of the biomass exclusive of soil.

Current accretion to soil N in litterfall and enriched precipitation was virtually the same for alder and mixed stands, yet average soil N accumulation over the life of the mixed stand was only 23 pounds per acre per year — about one-fifth of that in the pure alder. We believe the explanation for this difference lies not in any substantial difference in N-fixing rates between the two forest types but rather in the nature of the stands. A minor but contributing factor influencing soil N beneath the mixed stand and pure alder is the difference in number of alder trees. The pure alder stand had 381 trees per acre with a total basal area of 157 square feet per acre, whereas the alder component of the mixed stand amounted to 363 trees per acre with 135 square feet per acre total basal area. Probably of greater significance is the fact that the mixed stand had a total (alder plus conifer) of 860 trees per acre more than twice the number in the alder stand — and a total stand basal area of 222 square feet per acre. Thus, the mixed stand offers much greater opportunity for nitrogen storage in the vegetative mass than the pure alder stand, especially the conifer component which does not shed foliage annually.

For at least the first 40 years of its growth, red alder, in its litterfall, annually contributes the equivalent of a heavy N fertilizer application over and above the amount normally cycled in a conifer forest on the same site. This added N is rapidly made available for tree nutrition and increases growth of associated conifers (Tarrant 1961). Other benefits noted from the influence of red alder on the ecosystem include increased soil organic-matter content and porosity (Tarrant 1961) and, possibly, reduction of the incidence of soil-borne pathogens that cause forest losses from root diseases (Li et al. 1967).

Before red alder was shown to be a biologically valuable component of managed forests, foresters often regarded it only as an undesirable intruder onto sites believed more properly to be reserved for production of conifers. Red alder has strong pioneering ability on newly bared lands because of its ability to supply its own needs for nitrogen, which usually is the major limiting nutrient element for good tree growth in Pacific Northwest forests. Because of its rapid early growth, unmanaged red alder can dominate associated conifer seedlings during early years of stand development. Thus, when alder reproduces naturally on upland sites, it may impede establishment of other tree species and thus hinder full forest production.

Chemicals are widely used to kill red alder where it interferes with growth of conifers, but cautions have been sounded as to the need for reappraising present concepts of large-scale brush eradication. Tarrant (1964) pointed out that even with substantial evidence of the soil-improving quality of many species of *Alnus*, study of its application to silvicultural practice has not kept pace with other forestry research. Youngberg (1966) observed that in most situations where brush and weed plants are removed to enhance growth of economically more valuable tree species, little or no thought is given to the loss of beneficial effects exerted by many of the plant species being eradicated. And, Egler (1964) was even more emphatic in his views: "foresters can be remarkably ignorant . . . of long-term reactions from the loss of nitrogen-fixing 'pest plants' such as alder."

We see no real conflict in divergent viewpoints on the value of red alder in Pacific Northwest forest management but consider the matter

rather as one in which understanding of the value of alder as a potentially useful adjunct to managed forest stands is not yet widespread. Like most other trees, alder can become a weed requiring control or it can be managed to produce a silvicultural and economic benefit. In view of the rapid conversion of wild forests to intensively managed systems in Pacific Northwestern United States, we suggest that the demonstrated ability of red alder to enhance forest soil fertility and forest productivity is a biological tool that we must learn to use effectively.

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Nitrogen content and total weight of litterfall were determined seasonally over 3 years in 40-year-old coastal Oregon forests of pure conifer (Douglas-fir, western hemlock, Sitka spruce), pure alder, and a mixture of the conifers and alder. Either in pure stand or as an admixture with conifers, red alder led to about a threefold increase in the amount of nitrogen circulating in litterfall.

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